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LECTURE

ON

Modern Applications of Chemistry to Crop Production

By

EDWARD JOHN RUSSELL, O.B.E., D.Sc., F.R.S.

(*Director of the Rothamsted Experimental Station*)

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FIG. 1. EFFECT OF FARMYARD MANURE ON TILTH. BARNFIELD MANGOLDS.

⩚ To the right of the arrow, farmyard manure is supplied: to the left, it is not. The resulting good tilth and additional moisture supply allow an earlier start in plant growth (p. 19).

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1922

The Lecture was delivered before the Institute of Chemistry at King's College, London (by kind permission of the Delegacy of the College), on 14th November, 1921. Mr. A. Chaston Chapman, F.R.S., President of the Institute, in the chair.

SYNOPSIS OF THE LECTURE.

In general, chemists have adopted two methods in applying chemistry to crop production; they have endeavoured to explain the processes found successful by farmers, and they are developing a science which the expert can use in improving old methods of crop production or devising new ones.

Much of the modern work arose out of the attempt, very successfully made by Lawes & Gilbert, 80 years ago, to explain the fertilising value of farmyard manure. They showed that it was largely due to nitrogen, potassium and phosphorus present; and on the basis of this result was developed the present day artificial fertiliser industry. Recent work however shows that this is not a complete explanation of the value of farmyard manure.

Certain effects are producible by farmyard manure which no mixture of artificials will give: a steadying of the crop yield, maintenance of the cropping power of the soil, improvement in the yield of clover and improvement of the tilth for root crops.

Considerable investigation has been made to ascertain the causes of these improvements; four possibilities are being investigated:—

1.—Some of the constituents other than the recognised nitrogen, potash and phosphate, may prove of value to the growing plant.
2.—The cellulose or some decomposition product may exert a special action on the nitrogen-fixing organisms in the roots of leguminous plants.
3.—The decomposition products of the cellulose may profoundly modify the colloidal character of the soil, thereby changing its physical properties.
4.—Farmyard manure influences the micro-organic population of the soil.

One of the most important technical problems before the agricultural chemist to-day is to increase the amount of organic matter in the soil. This is being attempted by the use of straw as manure, by utilising sewage, green manure, etc.

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Modern applications of Chemistry to Crop Production

THE application of chemistry to crop production goes back for many years: one of the first, if not actually the first, treatises on the subject having been written by the Upsala Professor Wallerius as far back as 1761. The modern period, however, began with the distinguished French chemist Boussingault, whose methods and discoveries formed the basis of much that was done subsequently. The development of the subject was mainly due to Lawes and Gilbert, whose careful and prolonged experiments on the fields at Rothamsted have furnished a body of data that has not even yet been fully explored, and which will keep the staff fully occupied for a long time to come.

In general two methods of applying chemistry to crop production have been used. The older and still the safer one consists in trying to explain the processes which the farmer finds to be successful. The more recent method consists in developing a subject, a science, which the expert can use in improving old methods of crop production, or in devising new ones. This method is much richer in possibilities than the older one, though it is beset with many risks and may make a man appear supremely ridiculous if he recommends on scientific grounds some course that ultimately turns out to be completely ineffective.

One of the great classical agricultural experiments was carried out by Lawes and Gilbert in the winter of 1843: it is still continuing and still furnishes new material for the investigator. Lawes & Gilbert started from the well-known fact that farmyard manure constitutes an admirable fertiliser for the growth of crops, and attempted to explain, or rather to express, this fact in the chemical language of their day. Analysis of the manure showed that it contained a large

quantity of combustible material that we should now call organic matter, and a small proportion of ash,—mainly potassium, sodium, calcium, magnesium,—with some phosphate, silica, etc. Three views were held as to its value; the oldest, going back to mediæval times, to the effect that the value of the manure lay in this organic matter; a second, expounded by the distinguished chemist Liebig, that it lay in the ash constituents; while the third, indicated by the work of Boussingault and favoured by Lawes & Gilbert, was that the effective constituents were the ash materials plus the nitrogen of the organic matter.

TABLE 1.—PERCENTAGE COMPOSITION OF FARMYARD MANURE.

	Ammoniacal nitrogen	Amide nitrogen	"Other" nitrogen	Total nitrogen	Dry matter	Ash	P_2O_5	K_2O
Fatting Bullocks	0·124	0·078	0·425	0·621	25·35	5·56	0·263	0·716
Milch Cows	0·091	0·027	0·290	0·427	19·44	4·17	0·193	0·436
Quantities (lb.) added per acre in an ordinary dressing of farm yard manure (10-15 tons per acre)	22–40			93–205			42–80	95–240

In order to test these views Lawes & Gilbert divided a field of wheat into equal-sized plots, of which one received farmyard manure at the rate of 14 tons per acre; another received the ashes of exactly the same dressing of farmyard manure; a third received the mineral matter of the ashes *plus* some of the combined nitrogen that had been dissipated on burning; while a fourth lay unmanured.

The results were very striking:—

BROADBALK WHEAT FIELD, 1843.

	bushels per acre Grain	cwt. per acre Straw
Farmyard manure	22	13
No manure	16	10
Ashes of farmyard manure	16	10
Ashes of farmyard manure + sulphate of ammonia to supply combined nitrogen	$26\frac{1}{4}$	$15\frac{3}{4}$

The ashes proved ineffective, but the ashes + the combined nitrogen acted at least as well as the farmyard manure; it is therefore these that constitute the fertilising constituents of the manure.

Thus Lawes & Gilbert solved the scientific problem. They did not however rest content with this; but, with characteristic energy, developed the result in such a way that led to most remarkable consequences. They saw that they could make up the effective mixture of mineral substances + nitrogen compounds without using farmyard manure at all. Calcium phosphate was then known to exist in large deposits in England, Spain, France, etc.; nitrogen compounds could be obtained from gas works, and potassium compounds from kelp, wood ashes, etc. Even in the 'forties farmers were unable to obtain all the farmyard manure they would have liked, and here was a most promising substitute. There was a further advantage. The original farmyard manure had to be applied at the rate of 14 tons to the acre, which would mean 300 tons on a rather ordinary sized field; the artificial mixture, however, was much more concentrated and only about 6 cwt. per acre was needed,—less than 7 tons over the field in place of 300 tons; an enormous difference in cartage, the significance of which will readily be appreciated by those living in the country. Lawes therefore started a factory at Deptford for the manufacture of artificial manures, and the industry thus launched has since grown to enormous dimensions, the output of fertilisers being:—

	PRE-WAR.		POST-WAR.
	World	United Kingdom	1920 United Kingdom
Superphosphate ..	10,000,000	800,000	
Basic slag	3,276,000	286,000	500,000
Potassium salts ..	4,000,000†	100,000*	
Sulphate of ammonia ..	1,300,000	60,000*	233,000
Nitrate of soda ..	2,500,000	80,000	104,000

* Equivalent to 23,000 tons K_2O.
† Equivalent to about 900,000 tons K_2O

FIG. 2. Increase of wheat crop caused by successive increases in dressing of ammonium sulphate.

FIG. 3. Influence of fertilisers of swedes:—Plot 1: Complete fertiliser; Plot 3: Phosphates and potassic fertiliser only; Plot 5: Unmanured.

The dressings usually given are in cwts. per acre:—

Superphosphate ..	2½— 5	2½ for cereals; 3—5 for swedes and potatoes.
Basic slag	5 —10	5 for arable land; 5—10 for grazing land.
Sulphate of potash or Muriate of potash ..	1 — 2	for potatoes, mangolds, clover, etc.
Kainit	3 — 5	for grassland, mangolds, etc.
Sulphate of ammonia..	1 —2½	1—1½ for cereals; 1½—2½ for potatoes.
Nitrate of soda ..	1 — 2	1 for cereals; 1—2 for hay, mangolds.

Agricultural chemists are rightly proud of artificial manures and have studied them with a completeness that deserves recognition. The problems fall under two headings:

1.—*The quantitative effects of artificial manures on crops.* Almost at the outset Liebig enunciated the view that the effect of manures would be proportional to the quantity used, —a rule which Lawes & Gilbert showed to be modified by the Law of Diminishing Returns.

This experiment has become classical; on the Broadbalk wheat-field a series of plots was laid out which received varying amounts of ammonium salts, but a constant and sufficient amount of phosphates, potash salts, etc. The yields of wheat have been:—

	1852—1864				1852—1912			
	Grain.		Straw.		Grain.		Straw.	
	Bushels per acre.	Increment due to 43lb N.	Cwts. per acre.	Increment.	Bushels per acre.	Increment.	Cwts. per acre.	Increment.
Full phosphates, potassium salts, etc., and in addition ammonium salts containing nitrogen per acre:								
none	18·3		16·6		14·5		12·1	
43 lbs.	28·6	10·3	27·1	10·5	23·2	8·7	21·4	9·3
86 lbs.	37·1	8·5	38·1	11·0	32·1	8·9	32·9	11·5
129 lbs.	39·0	1·9	42·7	4·6	36·6	4·5	41·1	8·2
172 lbs.	39·5	·5	46·6	3·9	—	—	—	—

FIG. 4. Effect of potassic fertilisers on the potato crop, Rothamsted, 1921 (dry season). Artificial manures alone used—no farmyard manure.

The results conform more nearly to the Sigmoid curve than to the straight line. A field experiment, however, is liable to many disturbing factors, and careful repetition is always necessary. Pot experiments are susceptible of greater accuracy, and from these Mitscherlich has recently argued that the effect is proportional to the disparity between the actual and the maximum attainable crop, and that therefore a small dressing of fertiliser would produce a large return because the total crop is still a long way from the maximum; while a large dressing would give a proportionately smaller return. This view has some attractive features, but it does not appear to be entirely correct. Later field work at Rothamsted indicates that the returns for successive increments of fertiliser increase up to a certain point beyond which successive increments produce smaller and smaller yields. The three possibilities are set out in Fig. 5. The question is not merely one of academic

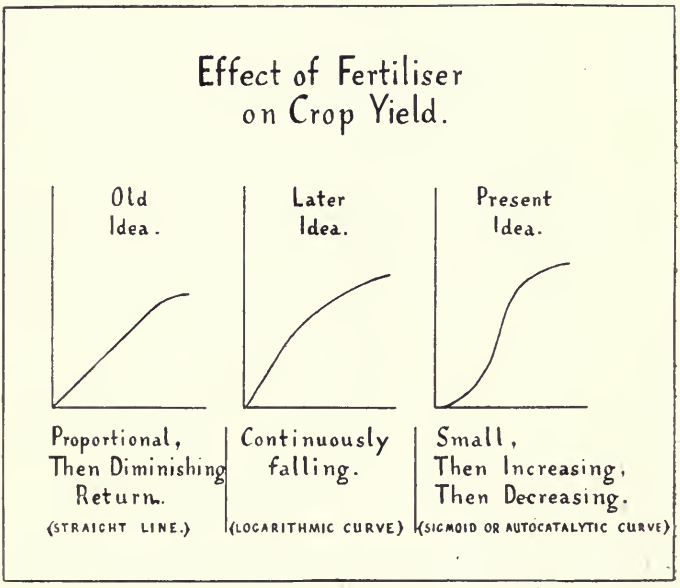


Fig. 5. Different views of the relationships between the quantity of fertiliser used and the yield of crop obtained.

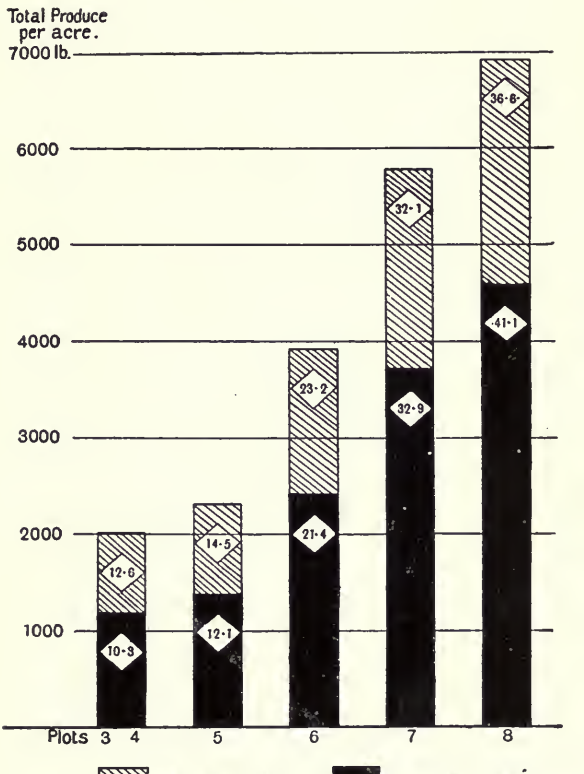
interest but of great practical significance, because on it turns the answer to the highly important question—What quantity of fertiliser ought a farmer to use per acre? A substantial dressing of fertiliser gives a larger crop than a small one, and from the point of view of food production this represents a clear gain. But the farmer must regard the process as a difference between cash expenditure and cash return, and the problem as he sees it is this—What expenditure per acre on fertiliser will give the largest profit? On Liebig's view all dressings are equally profitable up to a certain rather high limit; on Mitscherlich's view the small dressing will be most profitable; on the third view a moderately large dressing is best. The subject is of much practical importance, and is being more fully investigated at Rothamsted. For the complete solution of the problem pot experiments are insufficient as they necessitate the elimination of all factors concerned with the subsoil, natural water supply, drainage, etc., which are of great practical importance. Field experiments are therefore necessary, but they are conducted on the modern method of having small plots triplicated or, if possible, quadruplicated, and the experiments are divided into series so that the times of application of the fertiliser may be varied. Some of the results are:—

INCREASE IN WHEAT CROP 1920 FROM SPRING DRESSINGS OF SULPHATE OF AMMONIA AND SUPERPHOSPHATE.

Date of application of manure	Grain bushels per acre			Straw cwts. per acre		
	Feb. 10	Mar. 6	May 10	Feb. 10	Mar. 6	May 10
Single dressing ..	Nil	0·9	2·7	2·7	6·9	9·4
Double dressing ..	7·0	—	3·7	11·7	—	12·7

The qualitative effects of fertilisers are of equally great importance, though by their very nature they are less easy to investigate. Nitrogenous manures promote growth; they act almost instantaneously on the crop, making the leaves a more vivid green and causing more rapid growth of leaf and stem. When given in large quantities they lead to the production

of a dark green colour, to a habit of growth technically described as coarse or rank, and a tendency to the attack of fungoid disease such as rust in cereals. Phosphates improve



Effect of extra nitrogenous manure on yield of wheat. Rothamsted.

root development, an important property which finds many applications in practical agriculture, in virtue of which they play a great part in the growth of swedes and turnips. Further they hasten the ripening processes of grain; in consequence

they are needed for barley and for oats whenever early ripening is required, e.g. in cold wet districts. Another highly important property is to increase greatly the growth of clover in grass land; basic slag and mineral phosphates have revolutionised the treatment of British pastures. The demand for basic slag is so great that it has outrun supplies and a vigorous search is being made for substitutes. Mineral phosphates and low grade slags are being carefully examined. Formerly no judicious farmer would willingly have purchased an open hearth slag made with fluorspar, the phosphate of which is not very soluble in 2% citric acid. Pot experiments indicated that such slages were of less value to the plant than the more soluble products of the Bessemer converter. Field experiments have, however, shown that the difference is in practice less than was supposed, and the solubility test is no longer regarded as vital.

The classical experiments with basic slag were made at Cockle Park, the experimental farm conducted by Armstrong College, Newcastle-on-Tyne. Here a large area of very poor grassland, lying on the Boulder clay, and valued at the beginning of the experiment at 2s. 6d. per acre only, has been improved out of all recognition and enormously enhanced in value by a few dressings of basic slag. Some of the manurial results obtained are:—

	No cake No manure Plot 6	Decorticated cake* No manure Plot 1	No cake Basic slag (10 cwt. in 1897, 1905 and 1911) Plot 3
1st 9 years 1897–1905 ..	37	106·7	117
Increase due to manuring ..	—	69·5	80
Next 6 years 1906–1911 ..	23	42·5	117
Increase due to manuring ..	—	19·5	94
Next 6 years 1912–1917 ..	21·6	119	112·3
Increase due to manuring ..	—	97·3	90·7
Average annual gain 1912–18	—	Loss of 11s.9d. per acre	Profit of 27s. 5d. per acre

*597 lbs. cake per acre in 1897-8, in 1903, in 1904 and in 1912-14

Potassic fertilisers are associated with the production of carbohydrate; they therefore play an important part in the

manuring of the sugar beet, mangolds and potatoes: they seem to be of special importance for leguminous plants, and they increase the resistance of the plant to diseases, a property which is highly useful in the glasshouse industry. Some of Dr. Bewley's results at the Cheshunt Experimental Station are as follows:—

PERCENTAGE OF TOMATO PLANTS AFFECTED BY BACTERIAL STRIPE DISEASE.

	Complete fertiliser	No potassic fertiliser
Var. Comet	33	65
,, Kondine Red	11	28

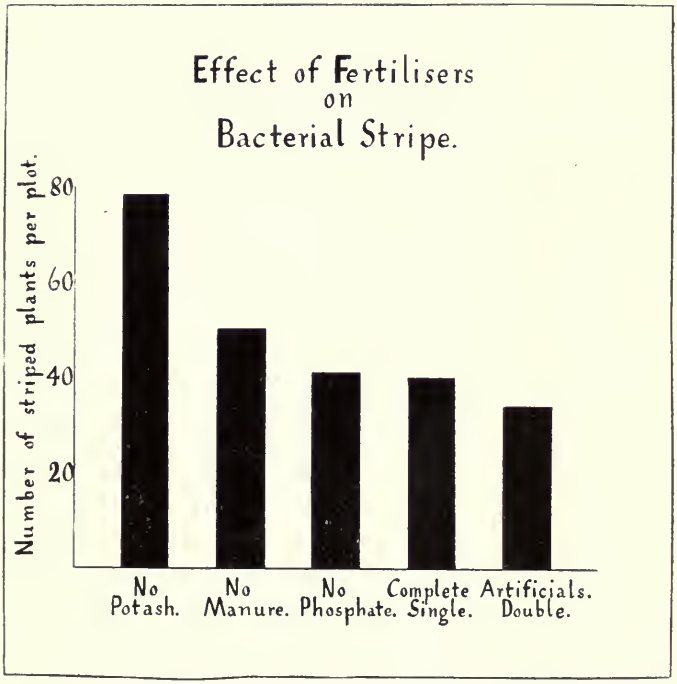


FIG. 7. Showing the marked effect of potassic fertilisers and the smaller effect of phosphatic fertilisers in overcoming "stripe" disease in Tomatoes. W. F. BEWLEY.

So satisfactory have artificial fertilisers proved that agricultural chemists have sometimes thought they represented all that there is in agricultural chemistry. Until very recently if a man proposed to speak on scientific agriculture it was expected of him that he would praise artificial fertilisers and disparage farmyard manure. Good farmers have always however insisted that farmyard manure has advantages over artificial fertilisers. Experience at Rothamsted confirms this. In looking back over the whole evidence it is clear that Lawes & Gilbert's deduction is to be regarded only as a first approximation. It is true that the plant nutrients contained in farmyard manure are mainly composed of nitrogen, phosphates and potassium, and that these can equally well be supplied by artificial fertilisers; it is not shown, however, that the only function of farmyard manure is to supply these nutrients.

Fortunately the continued repetition of Lawes & Gilbert's experiments year after year on the same ground has allowed of the accumulation of data from which evidence as to other effects can be adduced. Wheat has been grown for 78 years with farmyard manure and with various artificial manures. A statistical examination by Mr. R. A. Fisher in our laboratories of all the data accumulated since 1852 shows that farmyard manure gives rather more regular yields than artificials: the fluctuations from season to season are not quite so marked, and although the farmyard manure never gives "record" yields, it also never does very badly. Further, the plot fertilised with farmyard manure shows no signs of deterioration after 80 years of continuous cropping with wheat, while all plots manured with artificial fertilisers, even the best, show clear signs of deterioration now. (Fig. 8.)

Farmyard manure further appears to have a greater effect than artificials in increasing the growth of clover. Unfortunately the number of experiments on this is not very great, but the results are consistent, and the good effect is shown not only in the clover but in the succeeding wheat crop:

	After farmyard manure in 1915	After artificials in 1915
Clover, 1917, cwt. per acre	62·1	46·2
Wheat, bushels of grain per acre	45·1	37·1
,, cwt. of straw per acre	45·3	36·8

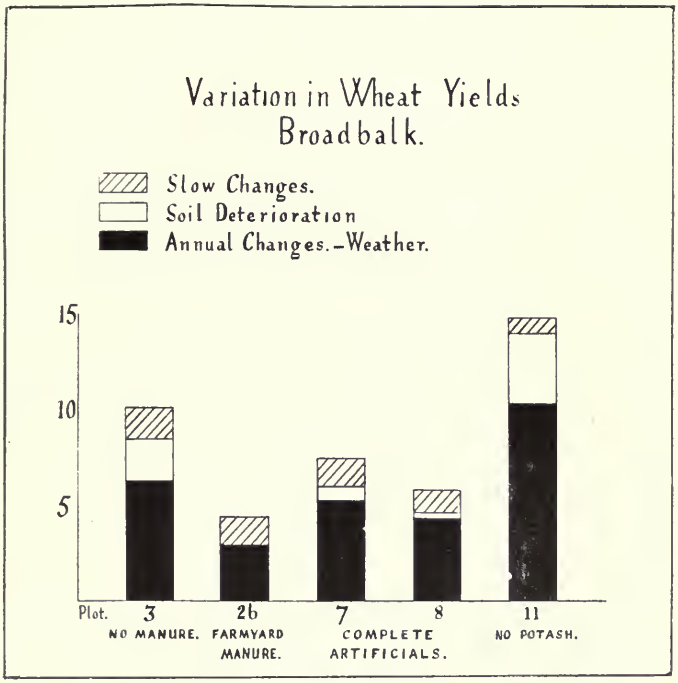


FIG. 8. Columns showing the amount of variation to which certain Broadbalk plots are liable, with an analysis of the relative effects of the various factors involved. R. A. FISHER.

Again, farmyard manure produces effects on root crops, and particularly on mangolds, which artificials will not give. On the Barnfield at Rothamsted there are 26 plots receiving artificials only, and 10 receiving farmyard manure. Up to the end of July the dunged plots stand out in sharp contrast with the others, showing a vigour of growth produced by none of the artificials.

All these facts,—and other which might be adduced,—go to show that the first generalisation in regard to farmyard manure, viz. that it owes its fertilising value to its nitrogen,

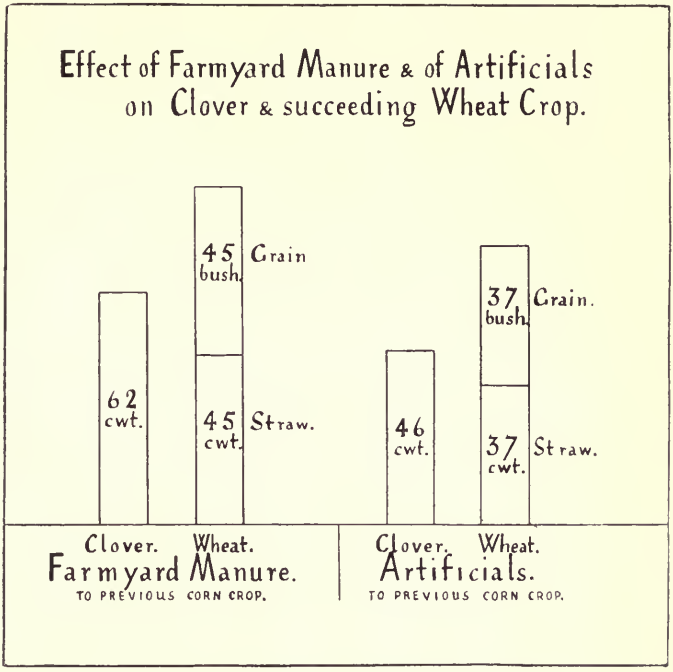


FIG. 9. Yields of clover and of the succeeding wheat crop on land which had previously received farm-yard manure, as compared with land to which artificial fertilisers only had been added. Little Hoos field, Rothamsted.

potassium and phosphate, does not express the whole truth. It has a large measure of truth and much pragmatic justification; it has given us our artificial fertiliser industry and in addition a great deal of our present agricultural chemistry; but there is something in farmyard manure which is not covered by this generalisation. Attempts are therefore being made to find out what causes these further properties: we are now seeking a second approximation.

It is of course possible that there are chemical constituents in farmyard manure which are essential or highly desirable to plants, but not present in our artificial fertilisers. The old idea that nitrate, potash and phosphates suffice for crop growth may be wrong. This aspect of the subject has been much investigated in France. G. Bertrand began it by classifying apart the "engrais complémentaires," which in present-day terminology would be called accessory substances. Manganese, fluorides, copper, have all been considered effective by the French workers. Recent work by Mazé in Paris and Dr. Brenchley at Rothamsted suggest that small quantities of boric acid may cause distinct increases in crops fully fertilised with artificial manures. We cannot as yet recommend farmers to adopt this kind of manuring with special substances, because it is very easy to overstep the beneficial limits, and then much damage is done to the crop; the effect seems to be rather in the nature of a stimulant than a food, and the plant suffers from excess just as surely as a man would do. However, it may prove possible to keep these effects within reasonable bounds and to ensure the same degree of control as we now have in the case of artificial fertilisers.

There is evidence that the cellulose in straw (which as litter constitutes about three quarters of the dry matter of farmyard manure) may be responsible for the special farmyard manure effects. It seems possible that the cellulose or some of its decomposition products may exert a special effect on the micro-organisms living in the clover root causing an increase in the amount of nitrogen fixation, thus giving larger clover crops and further enriching the soil in nitrogenous organic matter.

It also seems possible that certain decomposition products of cellulose are responsible for the remarkable physical effects which farmyard manure is known to exercise on the soil, causing it to become puffed up so that the empty pore spaces increase in size. The air supply to the roots thus becomes better, the water supply is more evenly regulated

the work of the tillage implements is lightened, and a good tilth is more easily obtained. The plots at Rothamsted receiving farmyard manure contain always some 2% to 5% more moisture than those receiving no manure or artificials only, and this enables the mangolds to keep growing during a drought which effectually checks all plants not receiving farmyard manure.

Lastly, there is a clear relationship between the supplies of farmyard manure and the population of micro-organisms in the soil. The importance of this population to the growing crop is only now being realised: it is known however that the farmyard manure and the green manure we put into the soil are not really agents of fertility but only raw materials out of which fertility is manufactured. The work is done by the myriads of living organisms in the soil, and their activity is increased by the presence of farmyard manure.

There are thus four possibilities to be investigated in regard to farmyard manure:—

1.—Some of its constituents other than the recognised nitrogen potash and phosphate, may prove of value to the growing plant;

2.—The cellulose or some decomposition products may exert a special action on the nitrogen fixing organisms in the roots of leguminous plants;

3.—The decomposition products of the cellulose may profoundly modify the colloidal character of the soil, thereby changing its physical properties;

4.—Farmyard manure influences the micro-organic population of the soil.

Work in all these directions is proceeding at Rothamsted and elsewhere. It is clear that the problem is much broader than was envisaged by the older chemists; in addition to the one factor of plant nutrients which they studied so thoroughly there are now known to be these four others which we have still to work out.

A good beginning has been made in the study of soil micro-organisms, and already we understand something of them and their work. There are two main lines of decomposition of interest to the agricultural chemist. One is the

decomposition of cellulose with ultimate production of the black material known as humus; the other is the conversion of the protein and other nitrogen of the soil to nitric nitrogen.

The first change is only slightly understood ; a plausible assumption for which there is some direct evidence is:—cellulose, ⩾ laevulose, ⩾ hydroxymethylfurfuraldehyde, which in presence of acids, e.g. amino acids, condenses to form humus. The second change is better understood. The complex compounds break down to form ammonia, which oxidises to nitrites and finally to nitrates. The agents bringing about the change are bacteria, and probably certain fungi; the production of ammonia is a widely spread property; it is not usual to identify the organisms concerned, but only to count them. The production of nitrite and nitrate is more specific and is confined to two or three species. Nitrates are an essential plant food and their production is indispensable to the plant. But the population is very mixed and some agents,—presumably some of the organisms,—remove part of the nitrate as soon as it is formed, either decomposing it, or more probably assimilating it and converting it into protein. Much light has been thrown on this process by a new method of investigation now in use at Rothamsted. Samples are taken from the field every two hours and determinations are made of the bacterial numbers and the nitrate. In the earlier work the ammonia also was determined, but its amount was always so small and so little subject to variation that the estimations were discontinued. In the cases so far examined the bacterial numbers and the nitrate show marked fluctuations, the nitrate following the bacteria up and down with a lag of about an hour.

The cause of the fluctuation in nitrate is the fluctuation in bacterial numbers: the experiment throws no light on the reason for this, but information is obtainable from another experiment. Counts have been made daily of bacteria and amœbæ in the soil for a period of 365 days; both fluctuated, but always in opposite directions,—when the amœbæ were

high the bacteria were low, and *vice versa*. Presumably the fluctuations in bacteria are caused by the fluctuations in amœbæ; but why the amœbæ should fluctuate we do not know; perhaps they are affected by some other organism in a way not yet known to us, or perhaps there is some internal cause.

While the upward movement of nitrate is the direct result of the upward movement of the bacterial numbers the downward movement can hardly be the direct consequence of the fall in numbers: presumably it is due to the operation of a destructive factor or organism such as had to be postulated to account for other Rothamsted results. It was found that the production of nitrate in the soil goes on steadily year after year when there is no direct addition of any nitrogen compounds to the soil: the stock of complex nitrogen compounds originally present seems sufficient to last for a very long time. Nitrate is being washed out from the drain gauges at an apparently uniform rate of 1 lb. of nitrogen per inch of rain, although for 50 years no nitrogen compounds have been added to the soil. No known hydrolysis of protein compounds could produce ammonia in this way, and the results led to the conclusion that part of the nitrate formed at any time is assimilated by micro-organisms, converted into protein, and then reconverted into ammonia and nitrate when they die. Recent work suggests that the amount of nitrate assimilation is much greater than was suspected. In a single day the amount of nitrate produced corresponded to 35 parts of nitrogen per million of soil, or 80 lb. nitrogen per acre,—as much as is required in a whole year by a 45 bushel crop of wheat; but in consequence of the destruction also going on the whole of this nitrate had disappeared before the end of the day and the net gain was *nil*.

There is reason to suspect that algæ may be concerned in the removal of nitrate,—which in this case would be by assimilation,—but other organisms may operate also; the matter is receiving close attention at Rothamsted. From the point

of view of microbiology it is of course essential to investigate as fully as possible these remarkable relationships.

Besides these organisms concerned in the nitrogen nutrition of the plant there are others that affect the health of the plant, causing injury or disease. We must now look upon the soil population as being both numerous and varied.

From the practical point of view it would be an obvious advantage to be able to control this soil population, and a beginning has been made here also. It is found that an improvement in fertility is obtainable when the soil population is simplified, as can be done by partial sterilisation by steam or organic poisons. The difficulty that the soil might become sterile through the action of the poison on the plant is obviated in practice by the interesting fact that certain of the soil organisms possess the remarkable power of decomposing such unlikely substances as toluene, naphthalene, phenol, cresol, and apparently even the chlorcresols, rendering them innocuous to the plant. These problems are all receiving attention at Rothamsted and elsewhere.

The rest of the four problems arising out of farmyard manure are also receiving attention, and already the scientific interest is considerable. We cannot help wondering whether these new problems associated with the nutrition of plants—the elements needed in minute quantities only; the influence of cellulose or its decomposition products on nitrogen fixation; the effect of farmyard manure on the soil population and on the soil colloids; whether these will turn out to be as important as the one that filled the vision of the 19th century workers; and whether when developed they will lead to the establishment of great industries like the artificial fertiliser industry, and to great agricultural developments like those resulting from the use of artificial fertilisers. The signs are hopeful, and there seems to open before us a vista of possibilities which if we could but grasp them would heal many of the ills from which we are now suffering.

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